National Aeronautics and Space Administration

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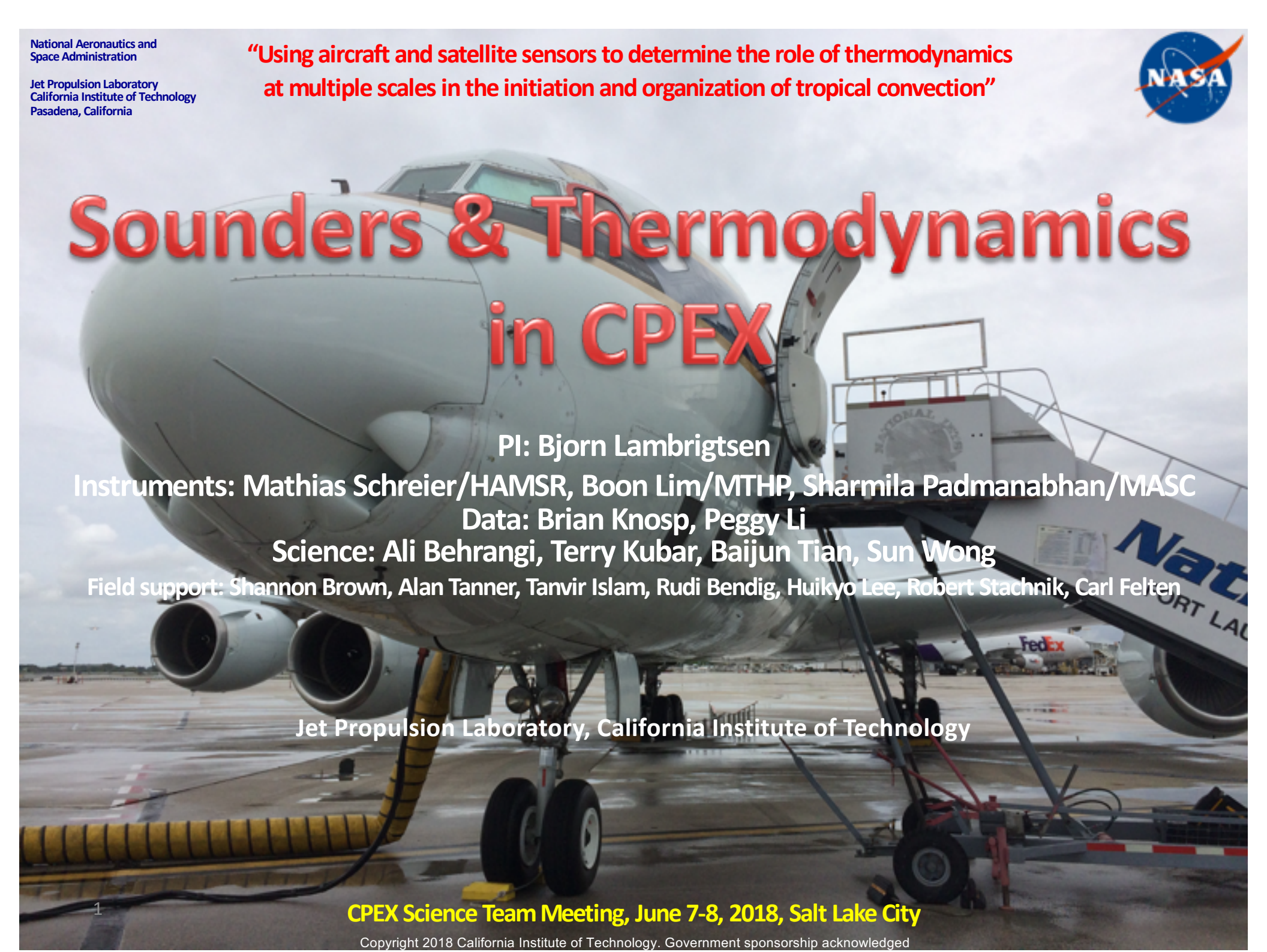
Pasadena, California

"Using aircraft and satellite sensors to determine the role of thermodynamics at multiple scales in the initiation and organization of tropical convection"



Sounders & Thermodynamics in CPEX

PI: Bjorn Lambrigtsen
Instruments: Mathias Schreier/HAMSR, Boon Lim/MTHP, Sharmila Padmanabhan/MASC
Data: Brian Knosp, Peggy Li
Science: Ali Behrangi, Terry Kubar, Baijun Tian, Sun Wong
Field support: Shannon Brown, Alan Tanner, Tanvir Islam, Rudi Bendig, Huikyo Lee, Robert Stachnik, Carl Felten

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CPEX Science Team Meeting, June 7-8, 2018, Salt Lake City

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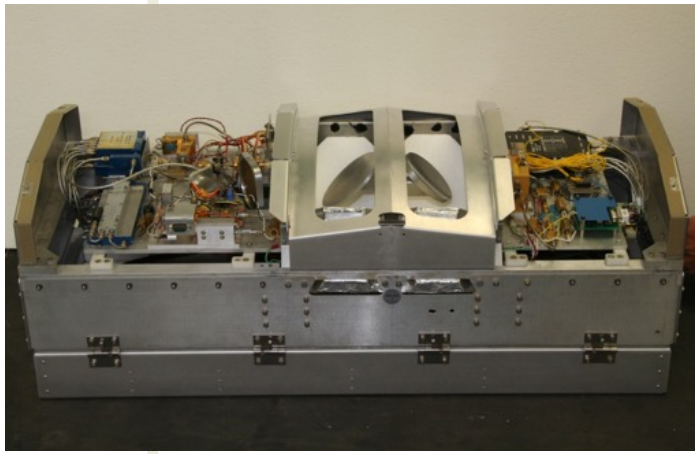
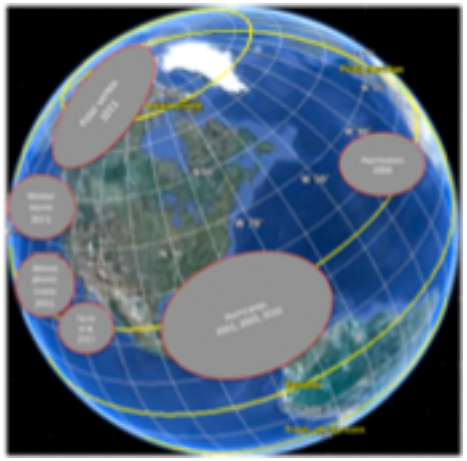
HAMSR Overview

High Altitude MMIC Sounding Radiometer

- Built under IIP-98 in 2001
- Pre-ATMS prototype
- Currently most accurate/sensitive MW sounder
  - Upgraded under AITT in 2010
- Flies on multiple platforms
  - Global Hawk
  - ER-2
  - DC-8
- Data transmitted from Global Hawk in R/T
  - Products displayed in R/T
  - V. useful for situational awareness



Now on the Global Hawk



Flown in many regions

Measurements

- Observations under all weather conditions
- Thermodynamic state of atmosphere
  - T(z), q(z), CLW
- Precipitation
- Convective structure
  - Reflectivity from hydrometeors
- Applications:
  - Hurricanes
  - Atmospheric rivers
  - Storms

Past and current campaigns

- CAMEX-4/Florida: Hurricanes **2001**
- TCSP/Costa Rica: Hurricanes **2005**
- NAMMA/Cape Verde: Hurricanes **2006**
- GRIP/California: Hurricanes **2010**
- WISPAR/California: **2011**
  - Atmospheric rivers
  - Pacific winter storms
  - Arctic science
- HS3/Virginia: Hurricanes **2011-2015**
- CalWater2/California: Atmospheric rivers **2015**
- SHOUT/CA, VA: Severe weather **2015-2016**
- CPEX **2017**

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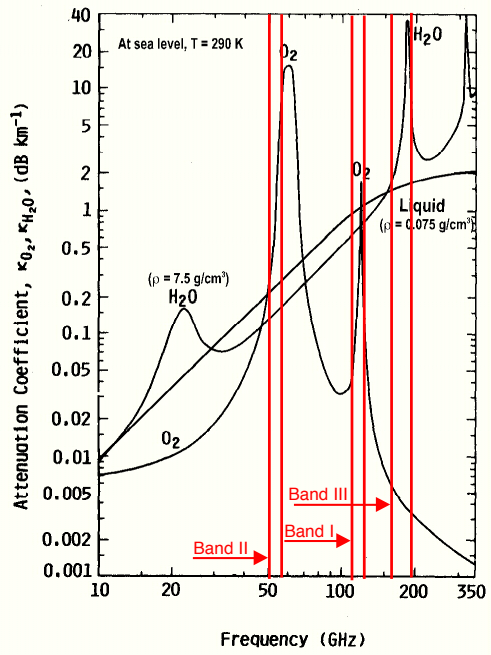
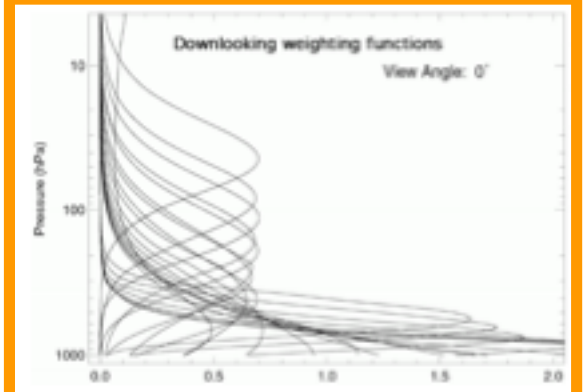
HAMSR Instrument Specs

HAMSR provides a 3D picture of the thermodynamic environment, convective structure & precipitation

Three spectral bands



Weighting functions



Direct measurements:

- **Brightness temperatures**
  - 25 channels
  - ~ 0.5 K cal. accuracy

Derived vertical profiles:

Surface to aircraft altitude

1-2 km vertical resolution
1-2 km horizontal resolution

Super-critical sampling

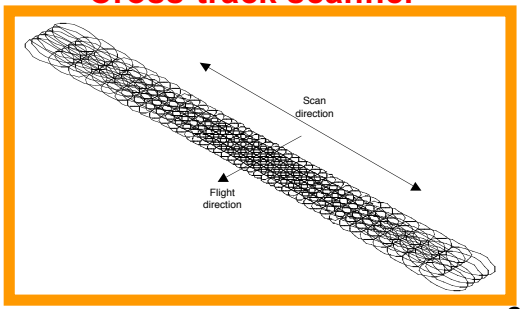
- **Temperature profiles**
  - Dual bands (50 & 118 GHz)
- **Water vapor profiles**
  - More accurate than AMSU-B
- **Liquid water profiles**
  - 3 bands ⇒ V. profile
- **Reflectivity profiles**
  - Experimental product

25 channels

Chan #	Center freq. [GHz]	Offset [GHz]	Bandwidth [MHz]	Wt-func. Peak [mb or mm]
I-1	118.75	-5.500	1500	Sfc/[30 mm]
I-2	"	-3.500	1000	Surface
I-3	"	-2.550	500	Surface
I-4	"	-2.050	500	1000 mb
I-5	"	-1.600	400	750 mb
I-6	"	-1.200	400	400 mb
I-7	"	±0.800	2x400	250 mb
I-8	"	±0.450	2x300	150 mb
I-9	"	±0.235	2x130	80 mb
I-10	"	±0.120	2x100	40 mb
II-1	50.30	0	180	Sfc/[100 mm]
II-2	51.76	0	400	Surface
II-3	52.80	0	400	1000 mb
II-4	53.596	±0.115	2x170	750 mb
II-5	54.40	0	400	400 mb
II-6	54.94	0	400	250 mb
II-7	55.50	0	330	150 mb
II-8	56.02 56.67	0	270 330	90 mb
III-1	183.31	-17.0	4000	[11 mm]
III-2	"	±10.0	2x3000	[6.8 mm]
III-3	"	±7.0	2x2000	[4.2 mm]
III-4	"	±4.5	2x2000	[2.4 mm]
III-5	"	±3.0	2x1000	[1.2 mm]
III-6	"	±1.8	2x1000	[0.6 mm]
III-7	"	±1.0	2x500	[0.3 mm]

⇒ Identical to AMSU ⇒ Equivalent to AMSU

Cross-track scanner



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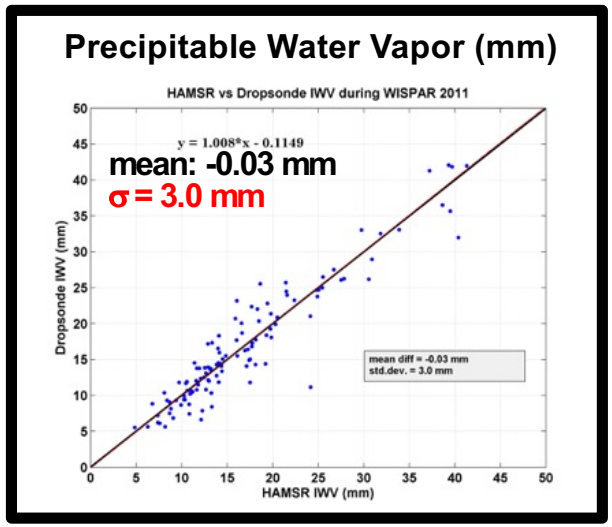
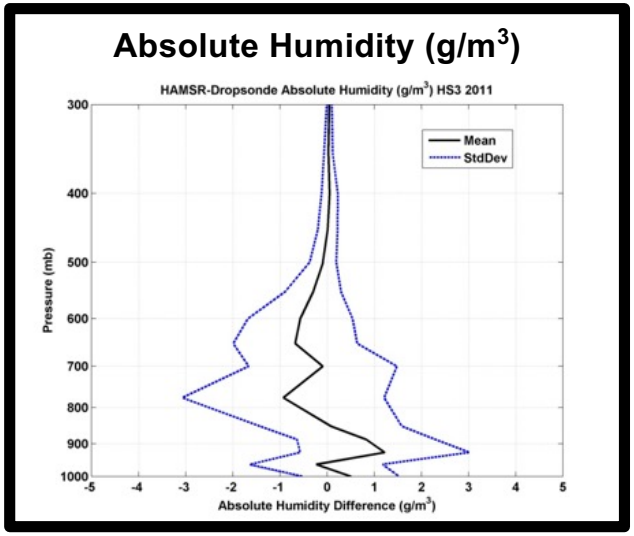
Thermodynamics: Accurate soundings

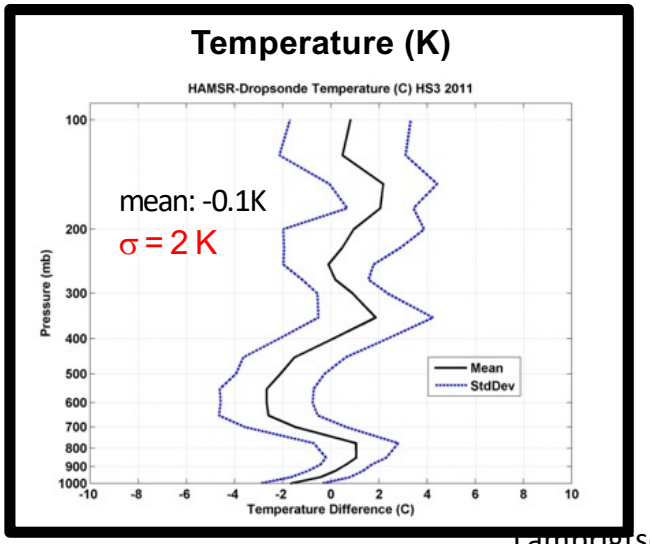
Sounders are normally used to determine thermodynamic structure:

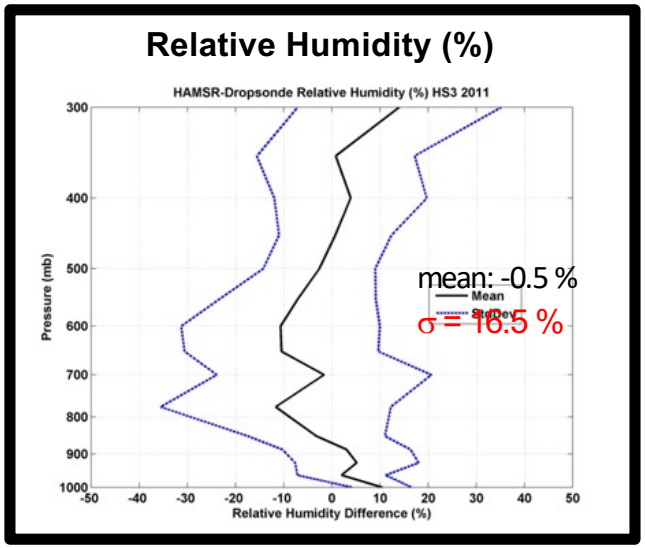
- Retrieval of 3-D atmospheric temperature, water vapor and cloud liquid water profiles using optimal estimation inversion approach
- Good agreement with dropsonde observations
- Vertical resolution (averaging kernels) is 2-3 km

- **50 dropsonde comparisons during HS3 over a wide variety of atmospheric conditions**
- **Dropsonde profiles smoothed vertically to match HAMSR vertical resolution**
- **HAMSR website contains validation reports for each flight**
- **Reports include comparison to MERRA and dropsondes T,q,RH**









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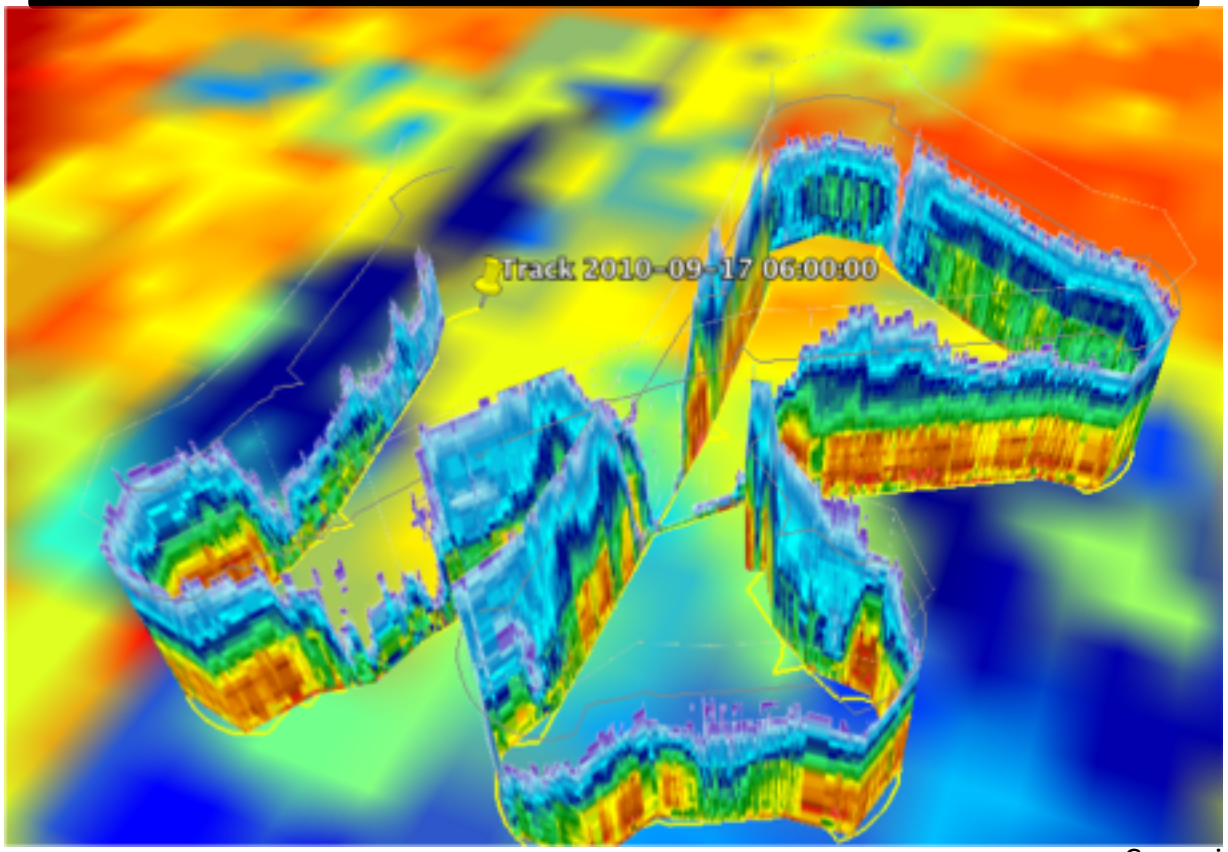
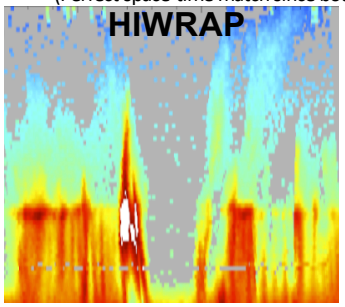
Reflectivity: Poor man's radar

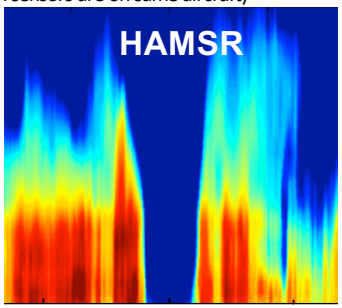
Vertical profiles of reflectivity across the full scan swath
- Resolution: 1-2 km; Precision: ~ 4 dBZ; Sensitivity: ~ 0 dBZ



Example from GRIP
http://grip.jpl.nasa.gov

Comparison with radar (HIWRAP) - H. Karl, 0644 UTC 9/17/2010
(Perfect space-time match since both sensors are on same aircraft)

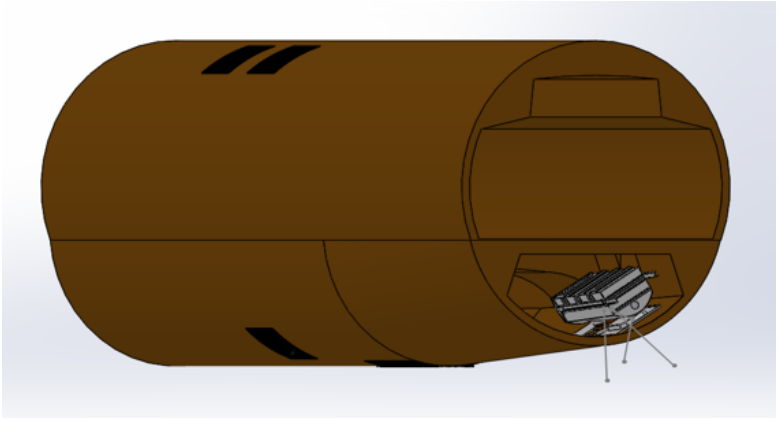




HAMSR reproduces all major structures, but at lower spatial resolution
including cloud top structure
including eye/eyewall structure
HAMSR has reduced sensitivity near surface
HAMSR has reduced sensitivity through stratiform structures

Installation

- HAMSR was installed with a slight angle
- ~ 31 degrees, was taken into account during lat/lon-calculation
- 65 usable scan angles (~ -30 to 30)



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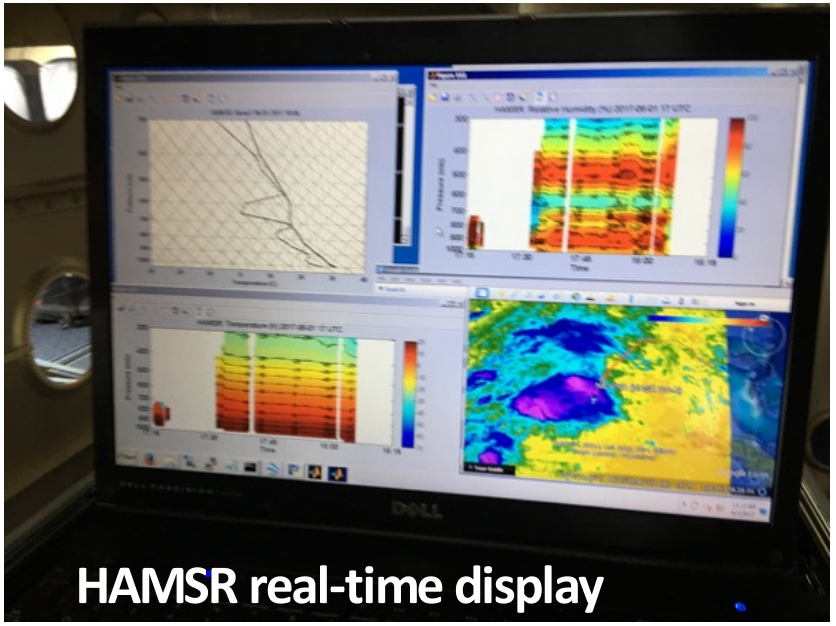
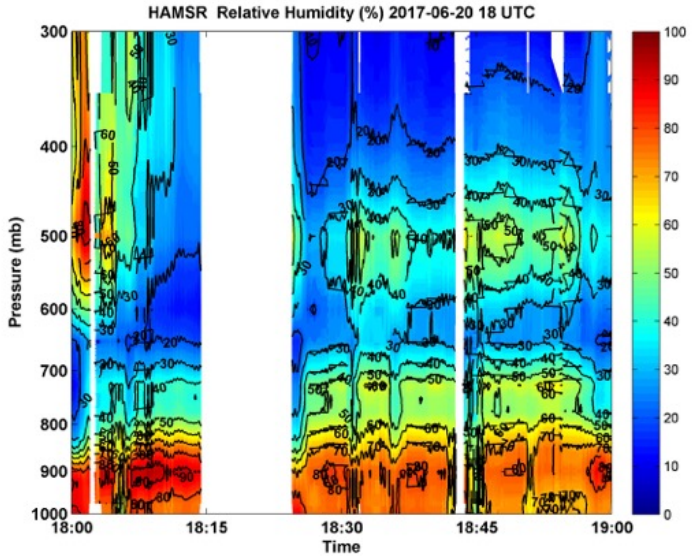
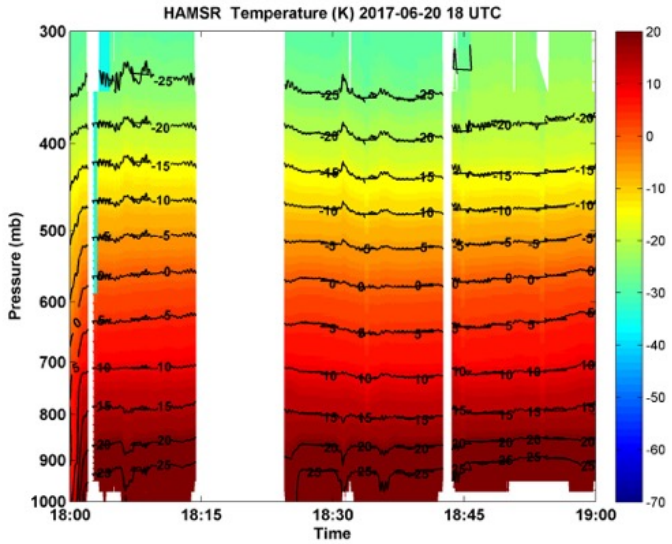
Real Time Data Overview

- netcdf-files (brightness temperatures, geolocation, t-, q- and rh- profiles, cloud liquid water, precipitable water)
- 1-hour-quicklooks available
  - (example for science flight #13 on 18UTC June 20th)







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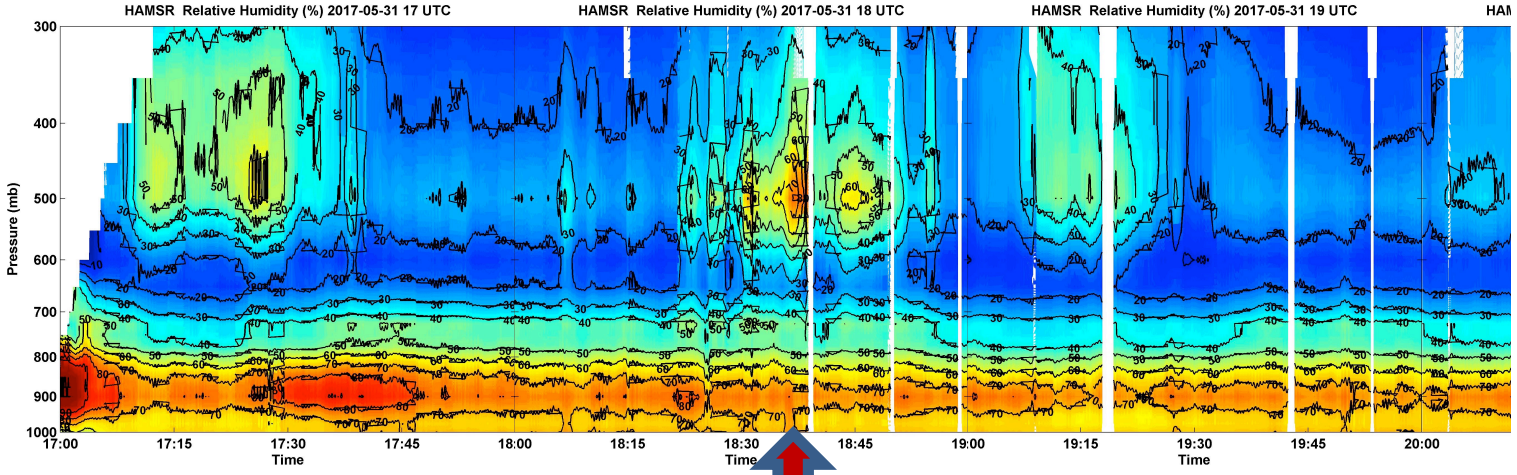
Highlight - 1



May 31, 2017

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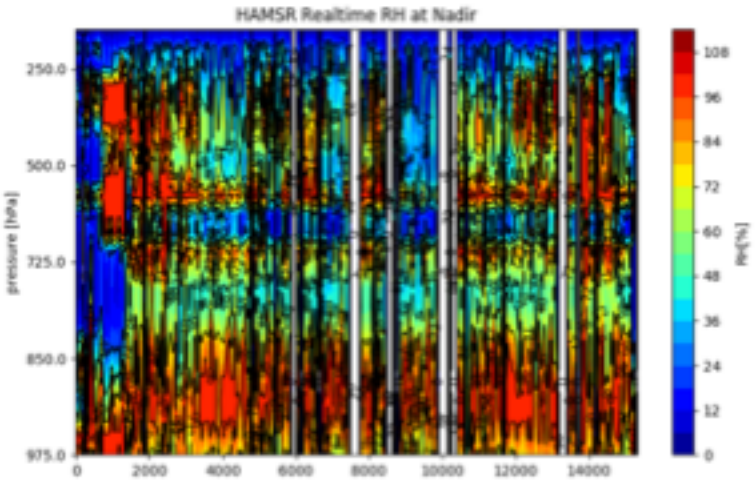
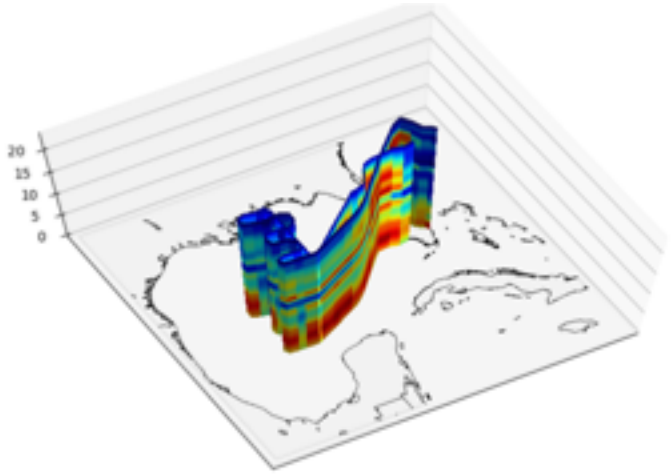
HAMSR Highlight - 2

- Example for science flight #8 on June 11th:
- Show cloud liquid water column (map) and RH for nadir (curtain and 3D-flightpath)
- Only minor gaps
- Area of investigation:
  - around -92º/24º is covered





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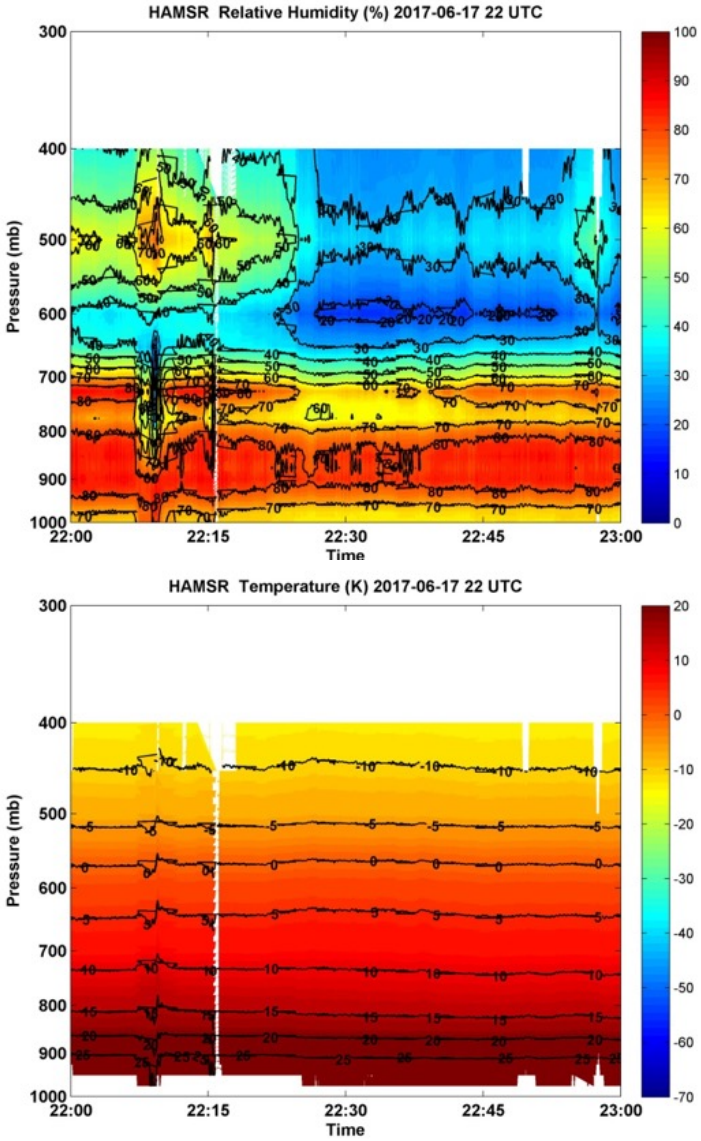
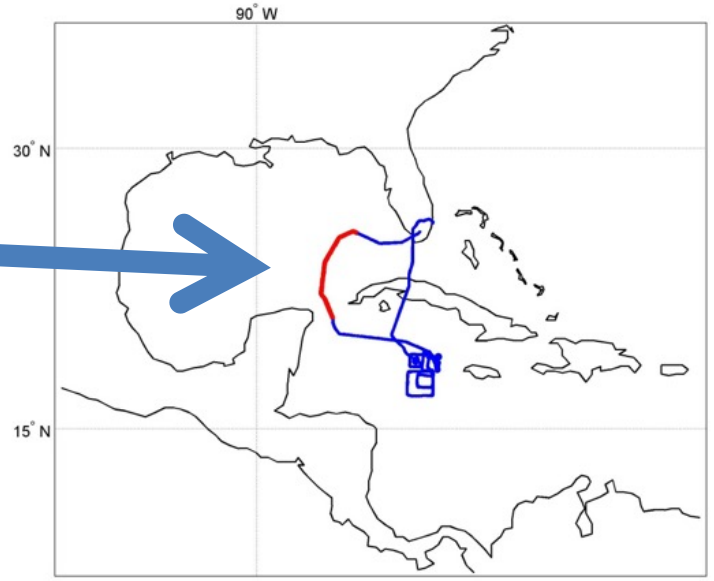
HAMSR Highlight - 3



June 17, 2017



Transition from mid-level moist air to dry on return leg

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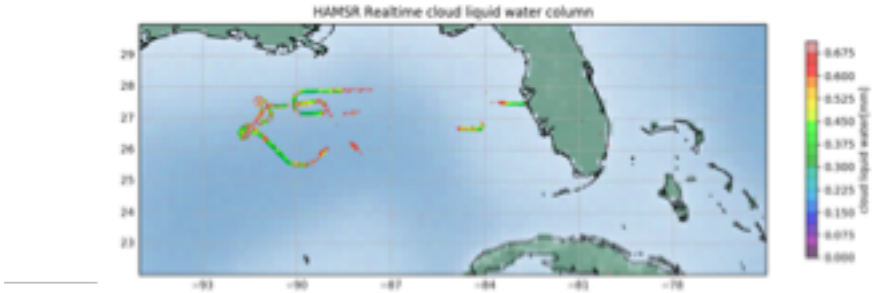
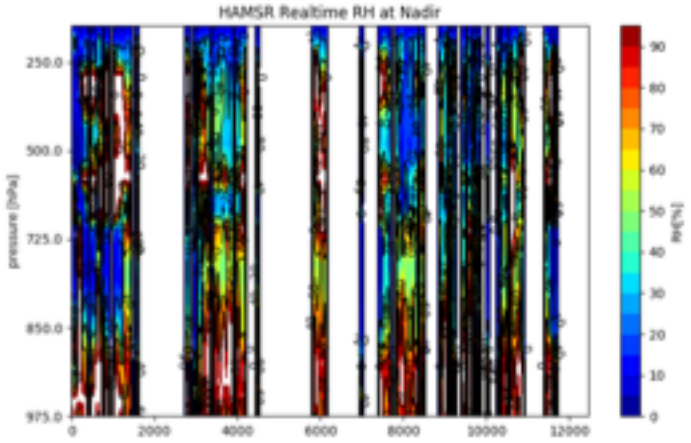
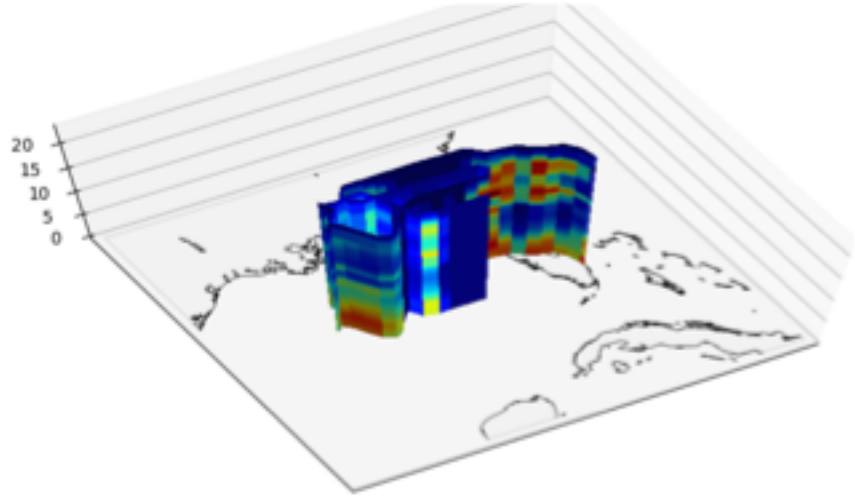
HAMSR Highlight - 4

- Example for science flight #13 on June 19th:
- Shown: liquid water column (map), RH for nadir (curtain and 3D-flightpath)
- Several gaps during strong rain and problems of 54.4 (visible in curtain plot/blue areas for 3D)
- Area of investigation
  - at around -90o/27o is covered
  - But has gaps







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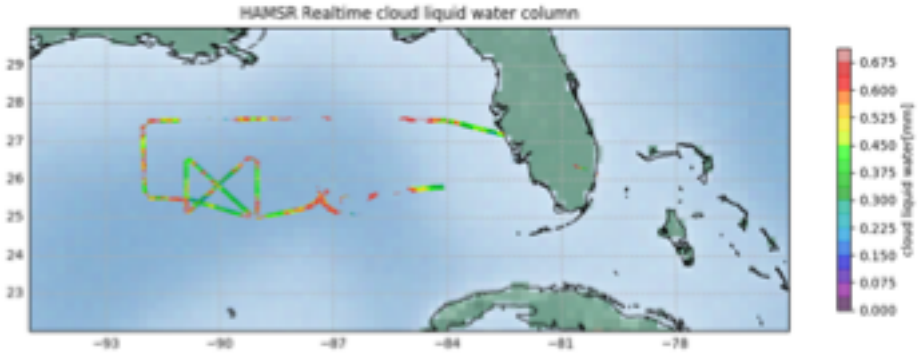
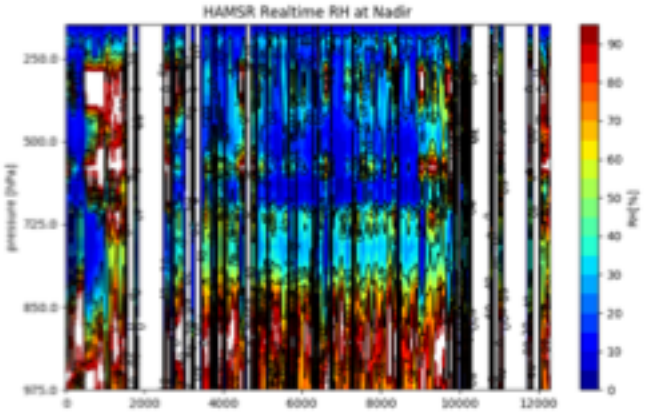
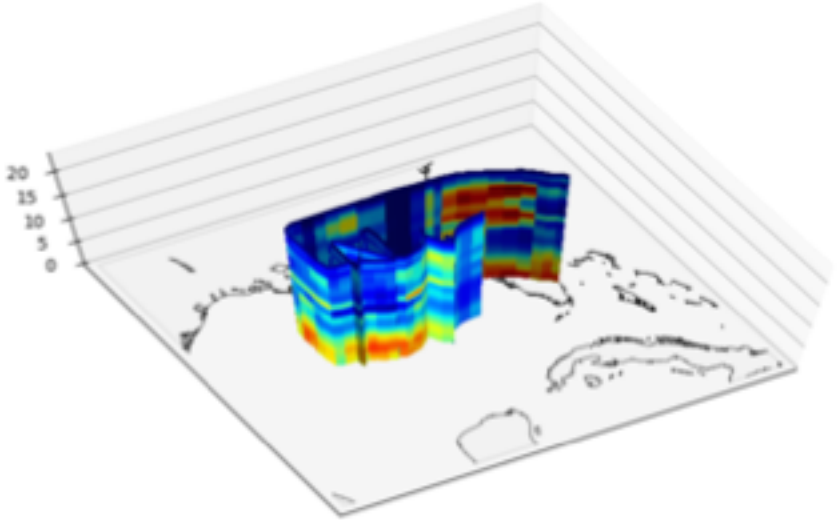
HAMSR Highlight - 5

- Example for science flight #13 on June 20th:
- Shown: T at 750hPa (map) and RH for nadir (curtain and 3D-flightpath)
- Only a few gaps, possible during strong rain
- Area of investigation
  - around -90º/26º is covered
  - Only a few gaps







HAMSR Post-processing

Primary: RATATOUILLE

Retrieval **A**lgorithm **T**estbed with **A** variety of **T**ransmutable **O**ptions to **U**nderstand **I**mpacts of **L**imiting components and **L**imitations from too high **E**xpectations

- Optimal estimation algorithm in development
- Uses CRTM
- Includes scattering, allows rain estimate
- Allows different background information (e.g. CYGNSS wind) for testing
- Allows channel selection (e.g. can eliminate 54.4 GHz after Flight #11)
- Gives error

Secondary: Neural network quick-looks, re-processed

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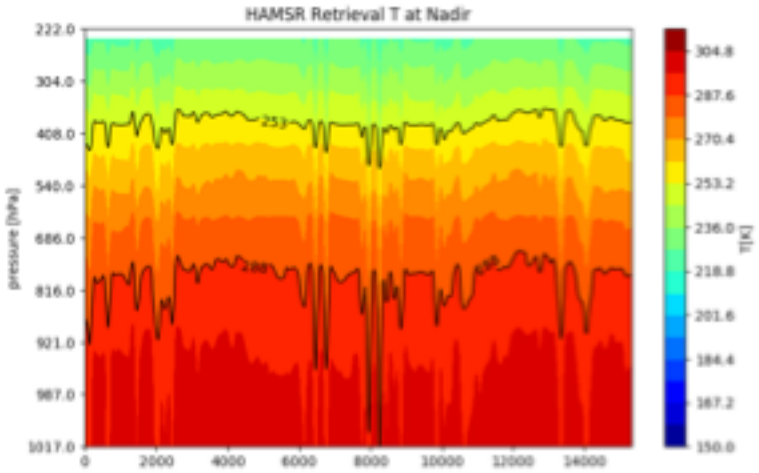
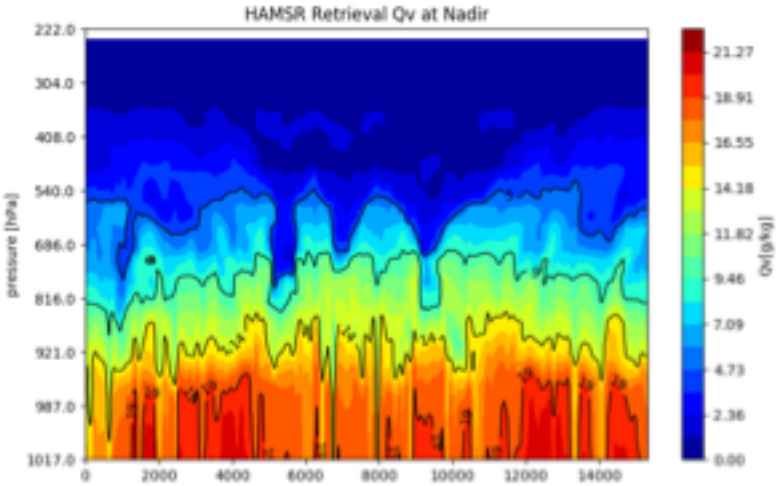
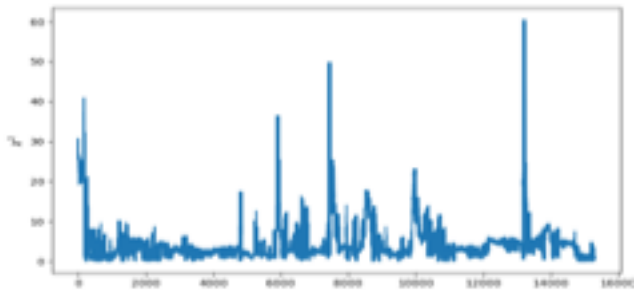
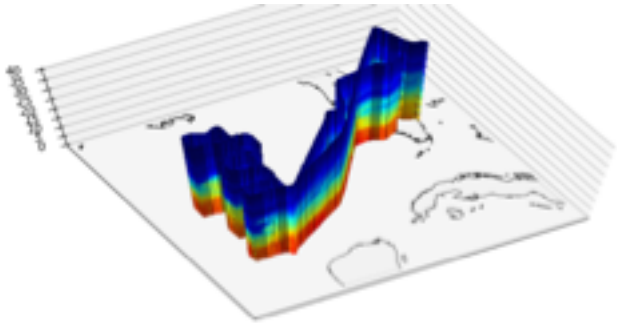
Post-Processing Example I

- Example for science flight #8 on June 19th:
- Shown: temperature (curtain) and qv for nadir (curtain and 3d)
- No gaps, still a little bit noisy
- Areas with large uncertainty are identifiable via error estimate









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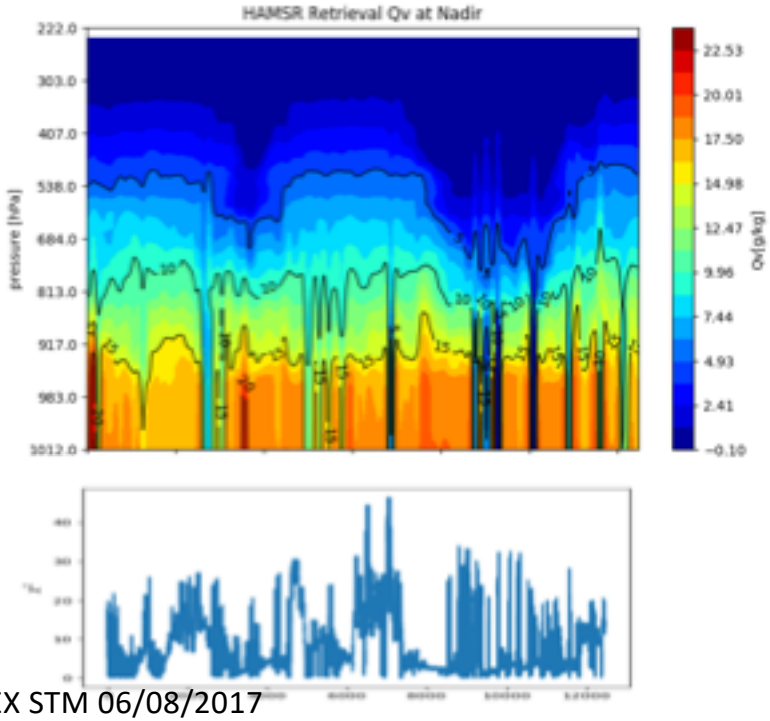
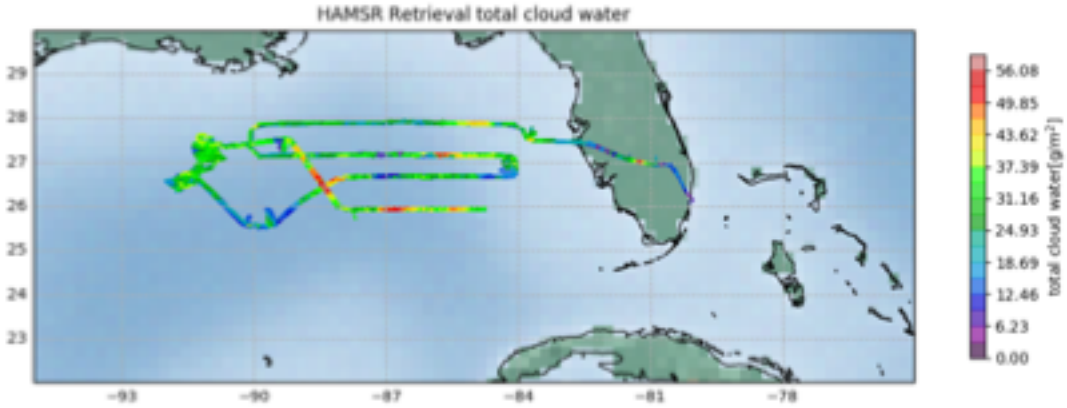
Post-Processing Example II

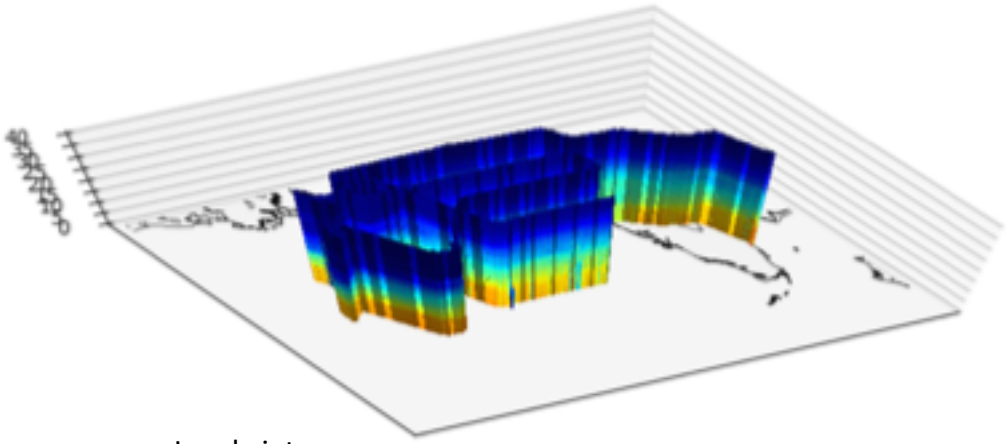
- Example for science flight #13 on June 19th:
- Shown: liquid water column (map), Qv for nadir (curtain and 3D-flightpath)
- No gaps, but sometimes noisy retrieval:
  - Regions with large uncertainties
  - sometimes unrealistic profiles

    =>Noisy channels on this day

    => channel selection needed







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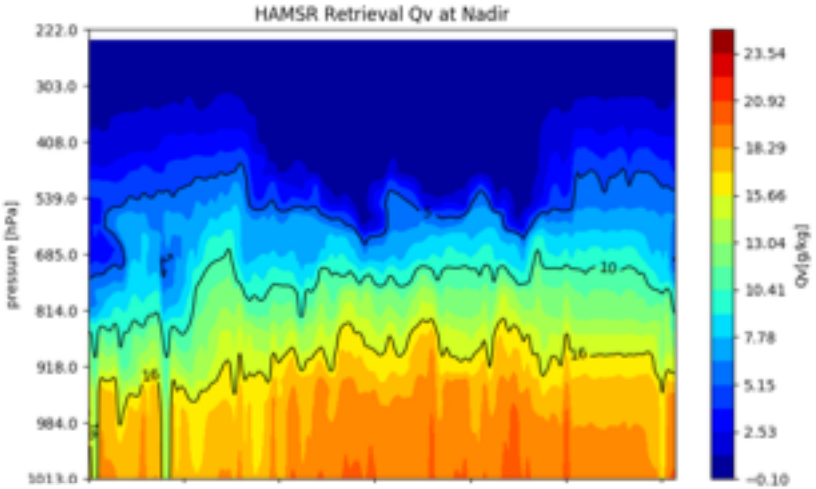
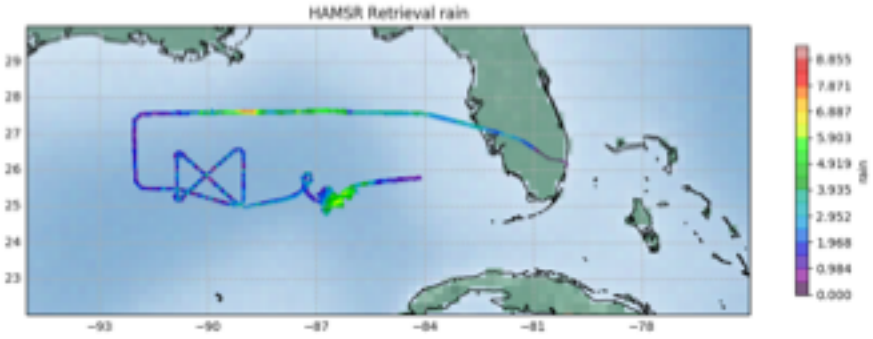
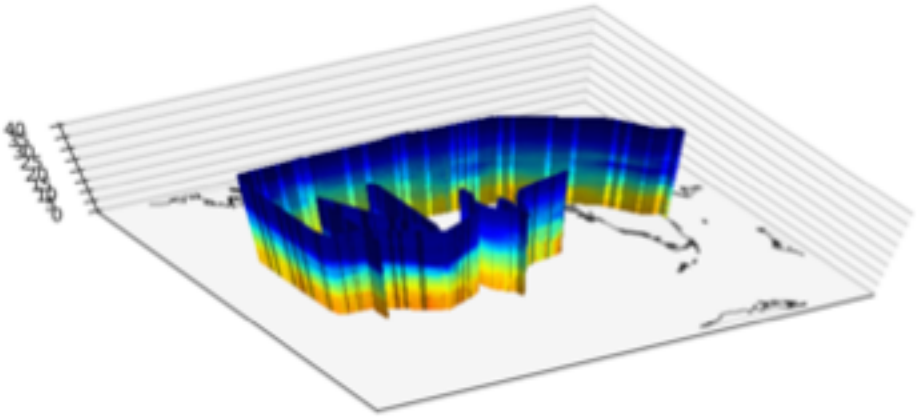
Post-Processing Example III

- Example for science flight #13 on June 20th:
- Shown: rain water column (map), Qv for nadir (curtain and 3D-flightpath)
- No gaps, low uncertainties during most of the flight
  - Uncertainty impacts in the first quarter and last quarter
  - Main focus area good





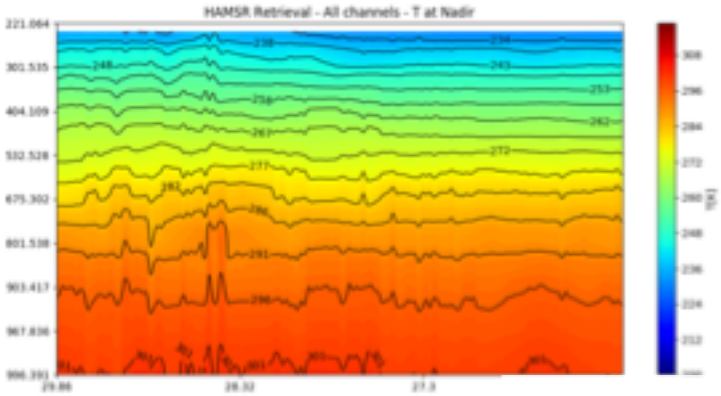


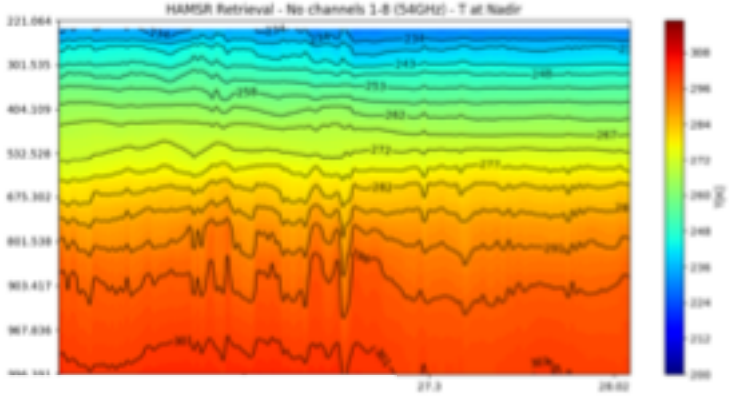
Post-Processing – Improvements

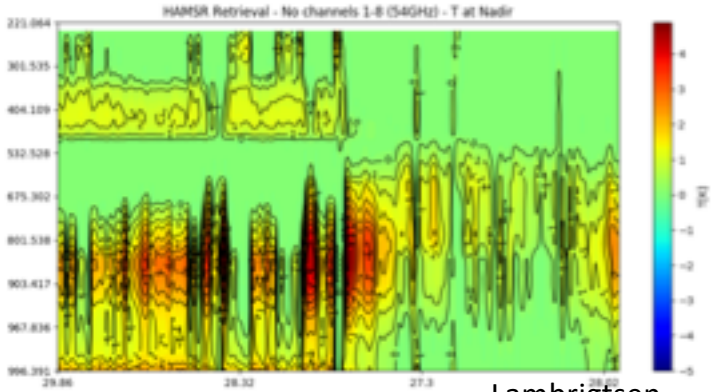
HAMSR allows to test the impact of “channel loss”, e.g. not using noisy channels

- Left side shows temperature-retrieval with all channels
- Right side shows the retrieval results of temperature without 54Ghz
- Bottom is the difference

  => More noise, impact on lower troposheric retrieval







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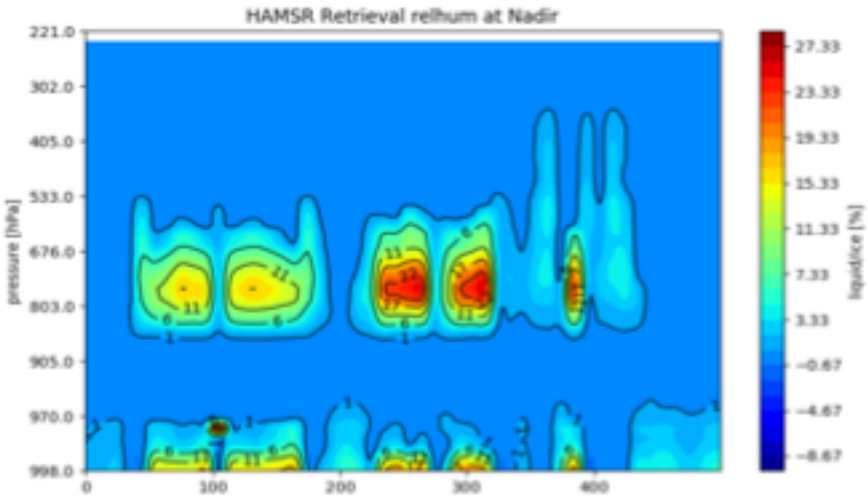
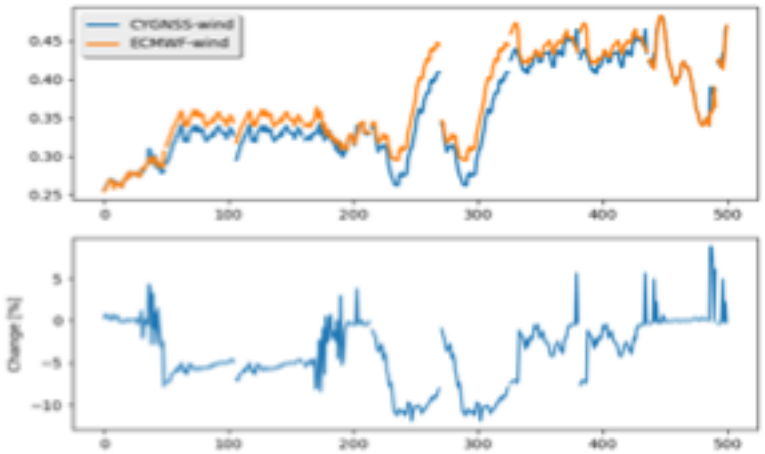
Post-Processing – Improvements

- RATATOUILLE allows the change of back ground conditions, like for example surface wind
- When using CYGNSS data, we can actually sometimes see an impact on the retrieval, but winds have to be strong
- Example is not CPEX flight, it is Hurricane Harvey



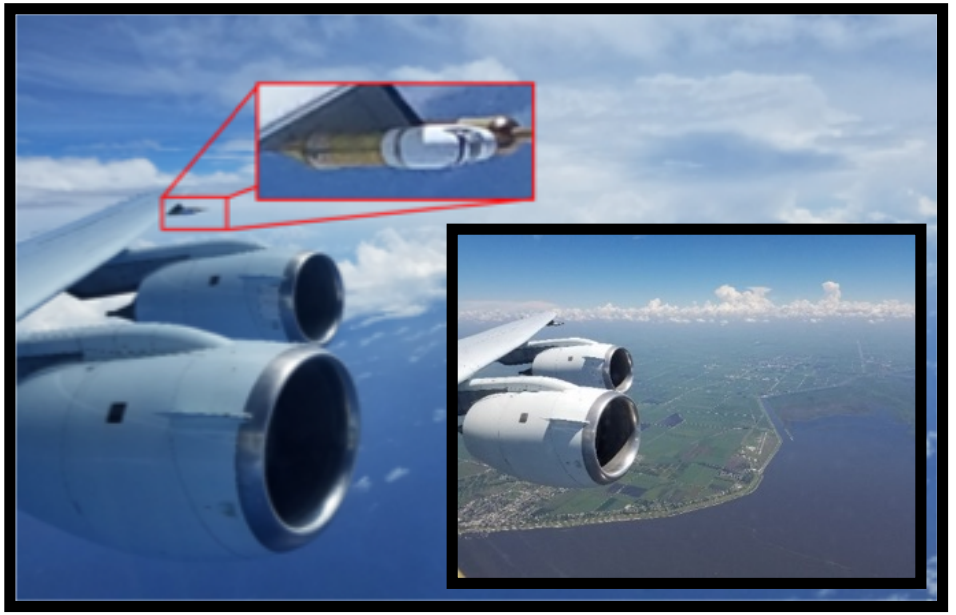


Post-Processing - Further Testing

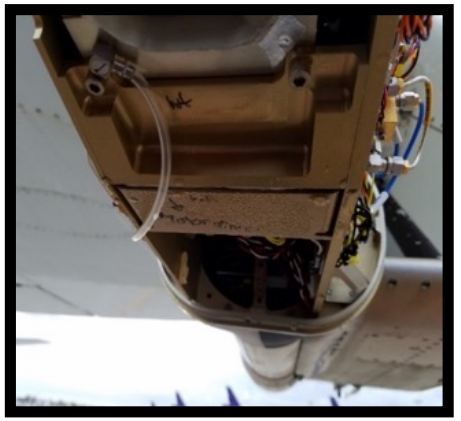
- Calculate without noisy channels
- Drop sonde comparisons
- Comparisons with radar to verify, if rain is at the “right place”
- Verify, if CYGNSS-data impacts the results

MTHP in CPEX

- Microwave Temperature and Humidity Profiler (MTHP)
  - Microwave radiometer that scans forward of the aircraft at 60 and 183 GHz (temperature and water vapor)
  - New capability, 'Humidity' capability to be demonstrated, experimental
- First installation on the DC-8
  - Flew on ~14 of 16 flights



- Nominal Operation ~75%, many lessons learnt
  - Severe environment on the wing + operation in icing conditions (insufficient heaters)
  - Interference from the aircraft (additional filtering will be implemented)
  - Catastrophic parts failures due to operation during landing in thunderstorm (SF #6)
- Synergy on CPEX
  - Dropsondes will provide in-situ comparisons below the aircraft
  - HAMSR and MAS are similar microwave instruments will allow for performance cross-comparisons
  - MTHP only microwave instrument that scans above the aircraft



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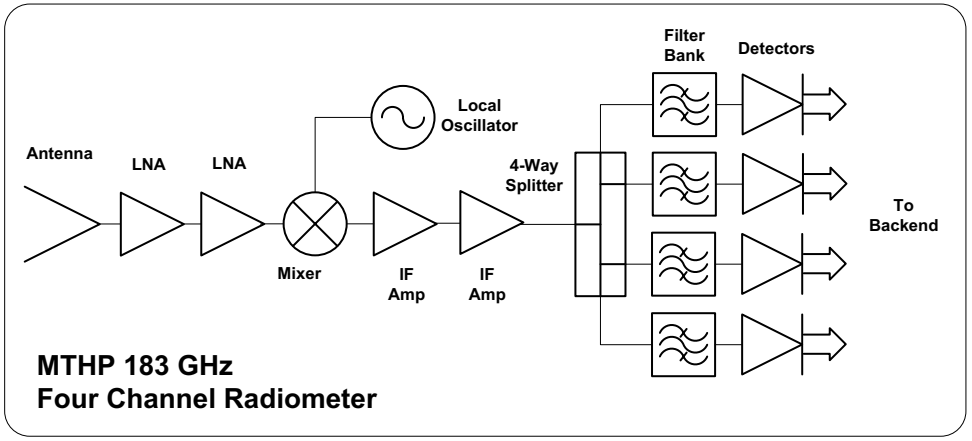
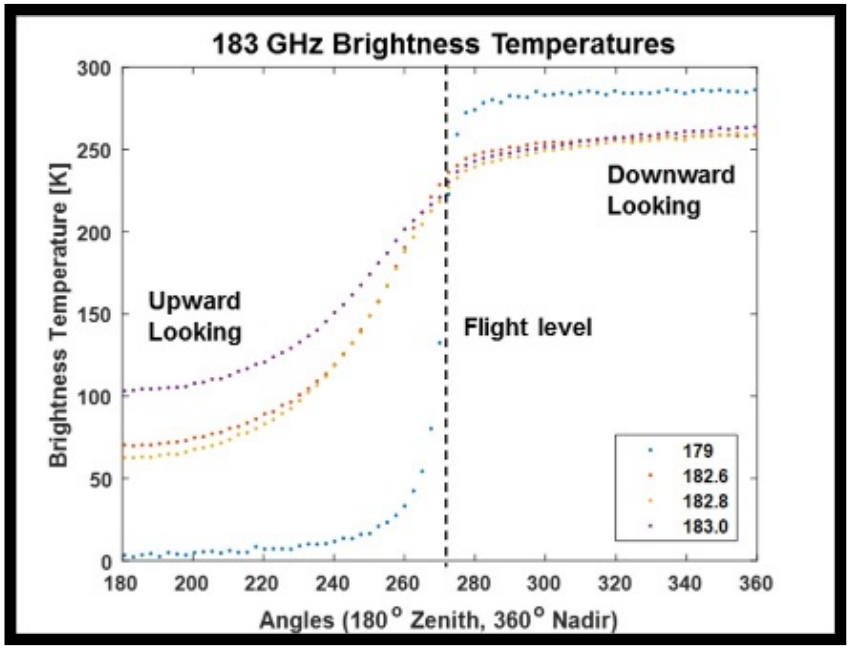
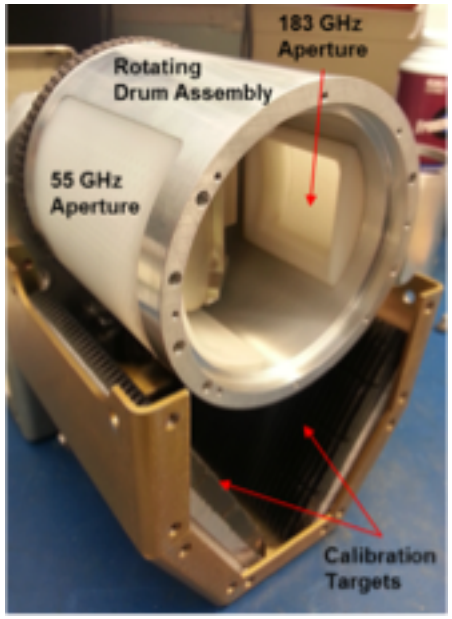
MTHP Key Capability

183 GHz Channels

- Enabling technology 35 nm InP HEMT amplifiers
  - Significant investment from NASA + others > $10 million
- Application of these technologies to instrumentation other than space
  - Both the 60 and 183 GHz channels upgraded







MTP vs MTHP Performance Comparison

	MTP	MTHP
Frequency Bands	60 GHz Only	60 and 183 GHz
Science	Temperature Only	Temperature and Water Vapor
Channels	3	8 (4 + 4) Configurable and Redundant
Technology	Mixer Front End	Low Noise Amplifier Front End
Calibration Path	Did *Not* Include Aperture	Full Signal Path Including Aperture
Single Scan Duration	~13 seconds (200 ms)	~1.5 seconds (10 ms)
Measurement	Series	Parallel
Angles measured	10	50 to 70
Scan Type	Stop and Stare	Continuous

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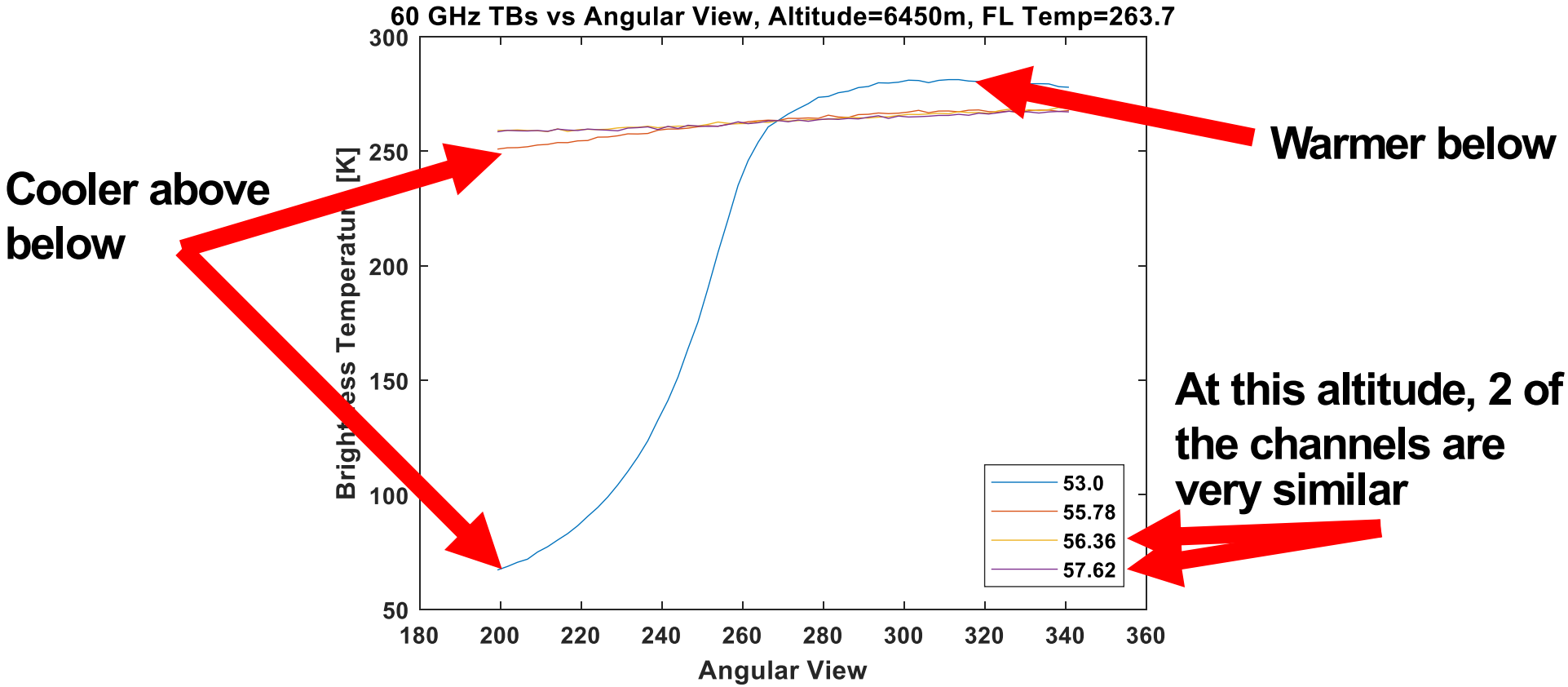
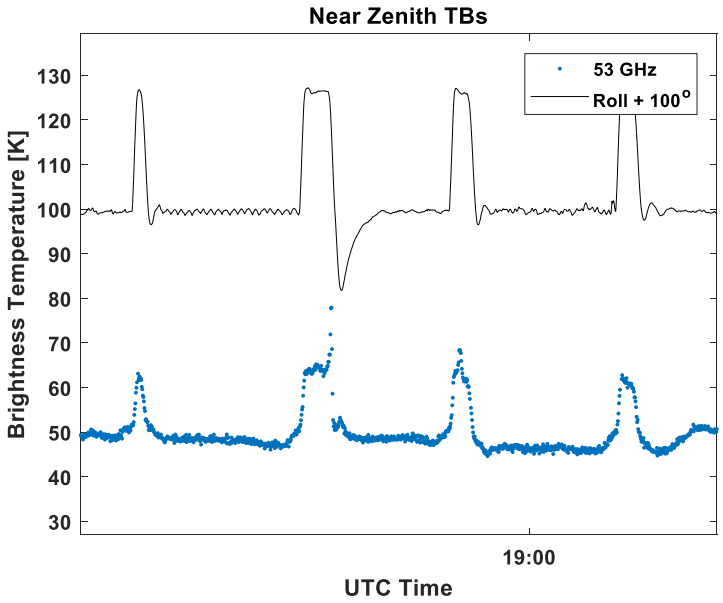
60 GHz Data Example



- ~270° is flight level (~180° zenith and 360° nadir)
- Single scan example shows a more transparent channel is necessary for sensitivity away from the aircraft, especially below the flight altitude
- 60 GHz NEDT ~0.7-0.8 K is higher than the expected 0.5 K

Data 'Sensitivity'

- Shown is the 53 GHz channel
  - 190º near zenith upward view
  - Changes in roll significantly impact the observations
- 'Easy' to integrate the aircraft data to flag for 'large' roll values



- Issues arise due to the installation
  - MTHP on the edge of the wing, during flight there is noticeable movement and flexing
- Extra quality control must be performed on the data to ensure that the aircraft motion is accounted for or discard data if there is a suspected issue

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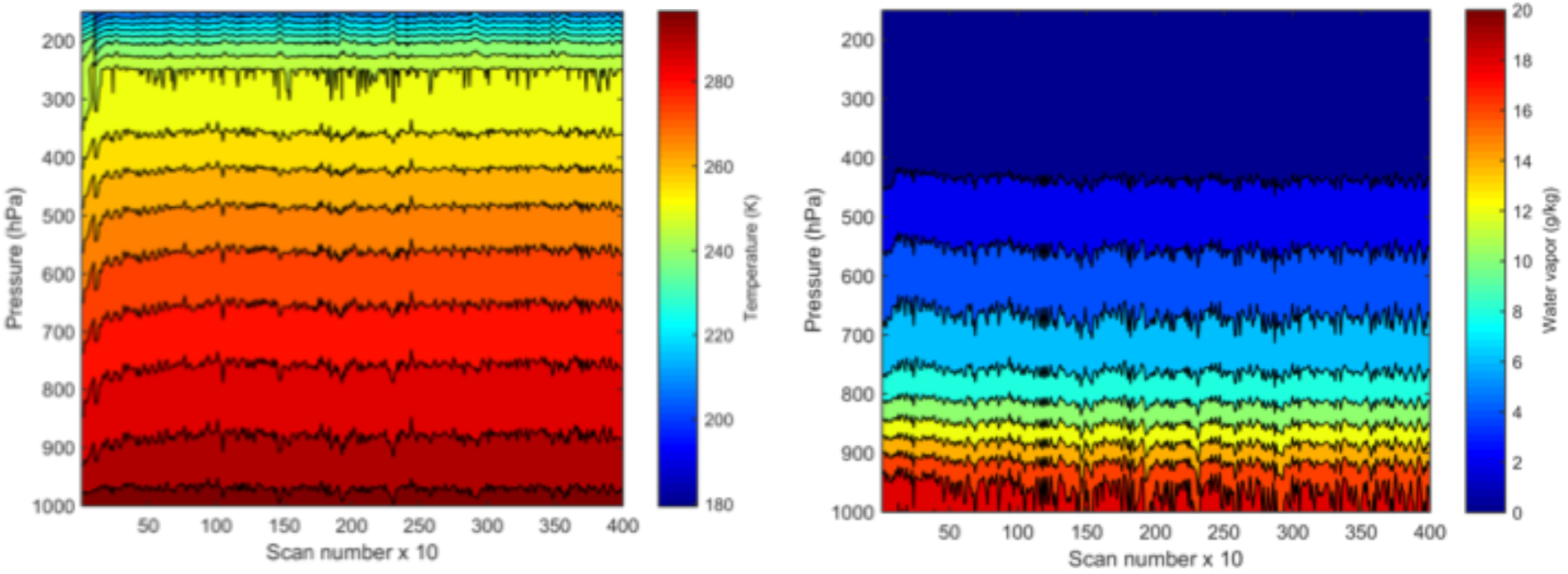
Preliminary Curtain Plots from SF#4



- Preliminary retrievals have significant ‘excess noise’ and expected structure is ‘washed out’
- New python retrieval framework still being optimized

MTHP Next Steps

- Complete the quality control of the data with appropriate flagging of the data for the aircraft maneuvers
- Refine the retrieval process with the automated comparisons to a priori
- Compare the output data with dropsondes
- Compare the output data with HAMSR and MASC

MASC in CPEX

- Instrument has been operating continuously and collecting measurements during all the CPEX flights so far.
- Minor momentary instabilities have been observed in the 118 GHz channels. Instrument was pulled out of the pressure box to check for any loose connections or fasteners but nothing conclusive was found on May 28.

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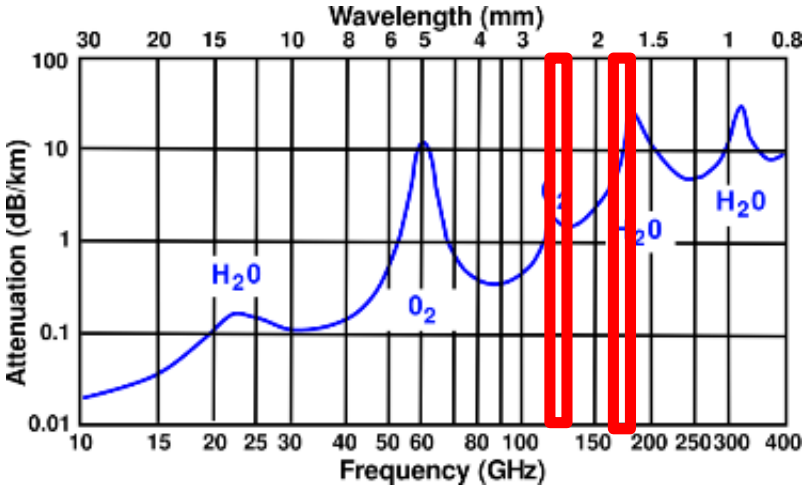
MASC Specs

2 Spectral bands



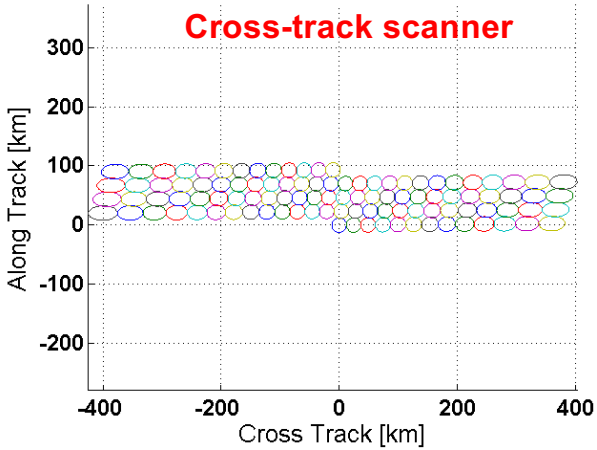
Direct measurements:

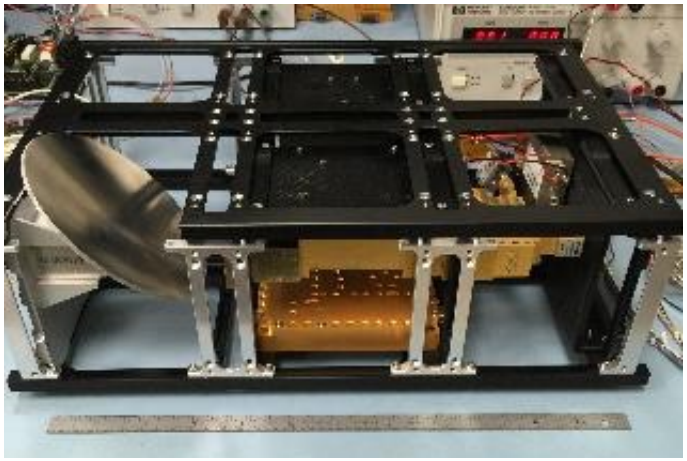
- **Brightness temperatures**
  - **8 channels**
  - **~ 0.5 K NEDT @ 5ms**

Derived vertical profiles:

- **Temperature profiles (118 GHz)**
- **Water vapor profiles (183 GHz)**

	118 GHz	183 GHz
System noise temperature	< 600 K	< 800 K
Minimum # of channels	4	4
Minimum spectral resolution	350 MHz	350 MHz
If Channels	+1, +2, +7 and +8 GHz	-1, -2, -7 and -8 GHz
Minimum Spatial resolution	24 km at nadir (orbit:400 km)	13 km at nadir (orbit:400 km)
Minimum Beam efficiency	>90%	>90%
Mass	5 kg	
Power	W	
Volume	3U	
Data Rate	10 kbps	





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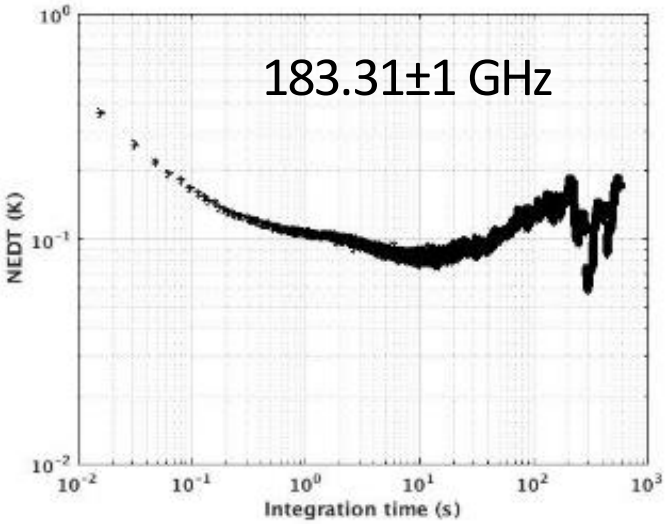
MASC Performance



Channel	NEDT [K]@100 ms
183.31±1 GHz	0.16
183.31±2 GHz	0.15
183.31±7 GHz	0.12
183.31±8 GHz	0.14
118.2±1 GHz	0.21
118.2±2 GHz	0.23
118.2±7 GHz	0.24
118.2±8 GHz	0.24

- NEDT plots for all channels are similar to the plot shown above for 183.31 GHz ± 1 GHz.
- Bandwidths are 390-400 MHz for all channels.

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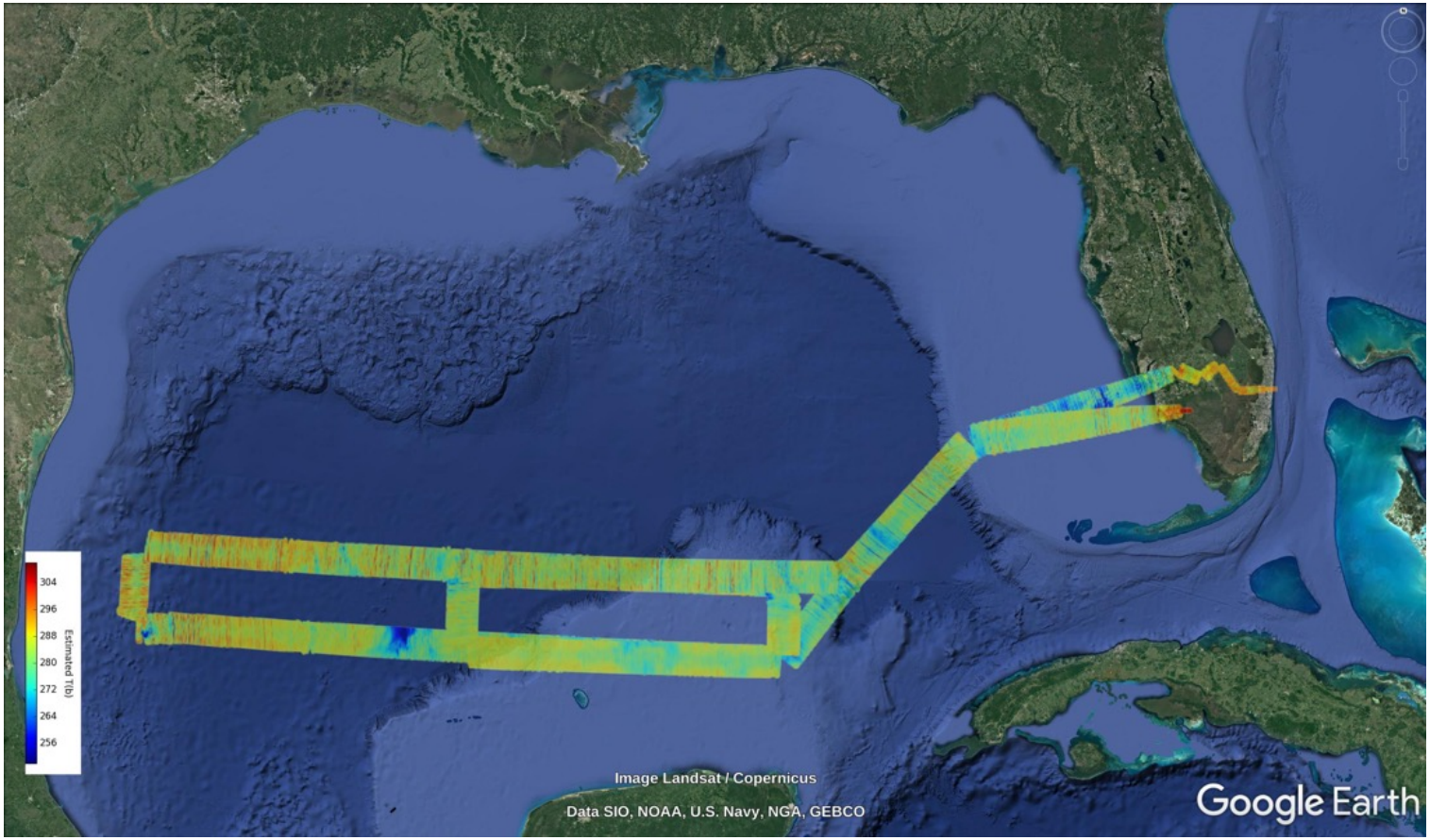
June 2: SCIENCE FLIGHT #4



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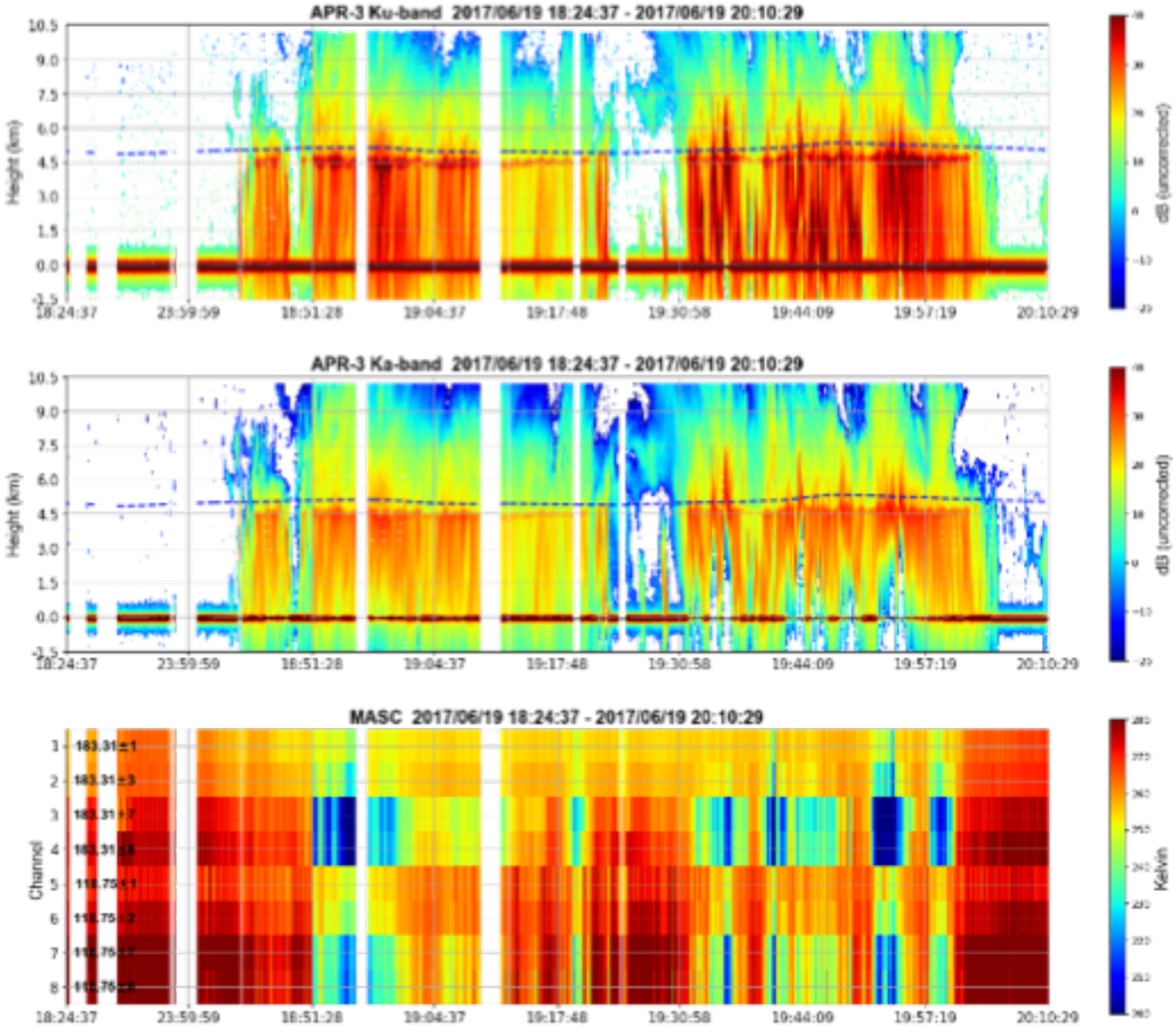
MASC TB compared with APR-3

Courtesy of
Dr. J Turk



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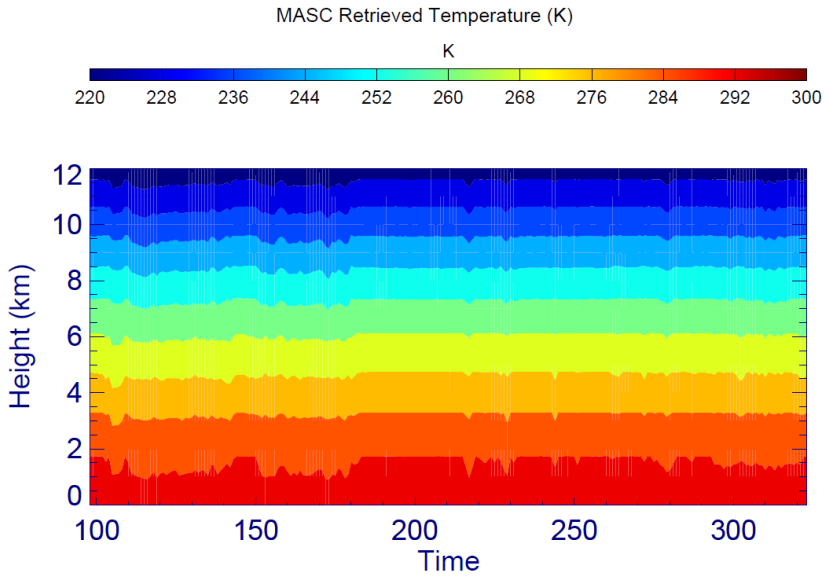
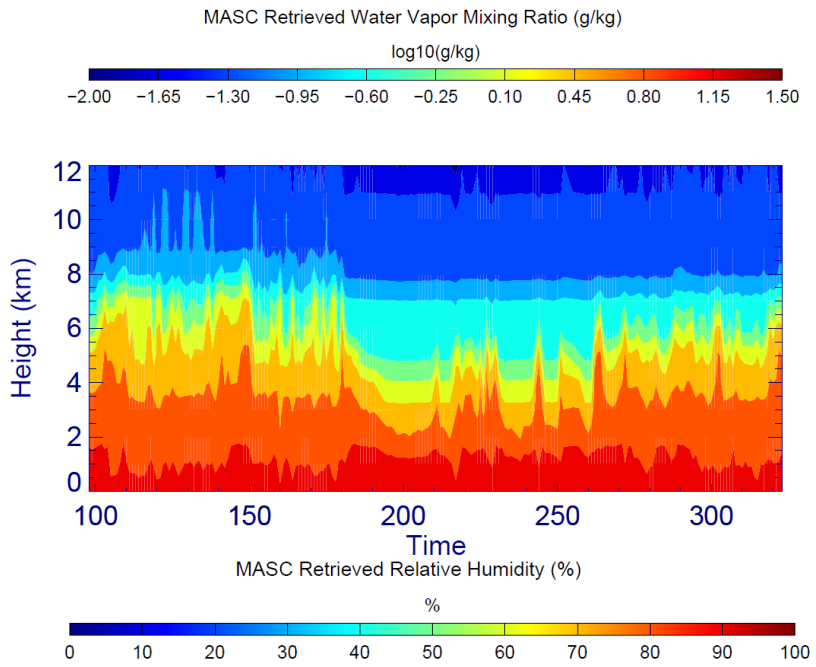
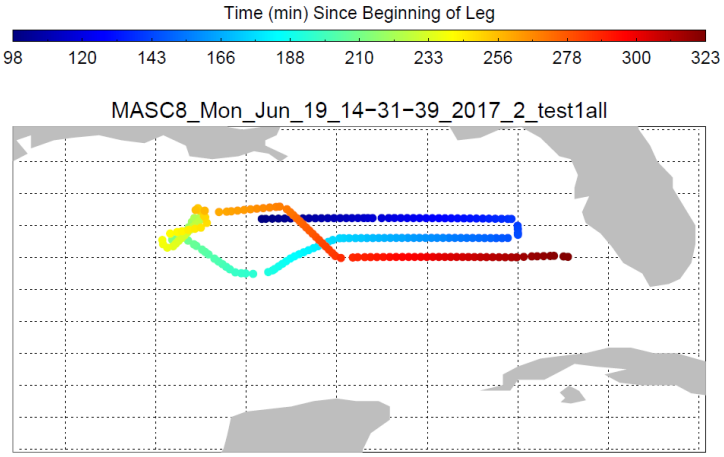
MASC Retrievals





- The MASC retrievals for June 19 measurements are shown.
- The time axis means minutes since beginning of the leg.



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Data: CPEX Website

https://cpex.jpl.nasa.gov

- Served as the official project website, offering the following res
  - Event Calendar
  - Flight and Science Summaries
  - Daily Forecast Reports
  - Quicklook Images
  - Information about aircraft and instruments
  - Team contact information and campaign image gallery
  - Links to related data resources – data portal, FTP server, model forecast pages, etc.

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CPEX FTP Server

ftp://mwsci.jpl.nasa.gov/outgoing/cpex

- Data is organized by instruments and dates/flights, including satellite data, CPEX data, and GFS model forecasts for easy download
- Satellite is data subsetted into the CPEX domain for the campaign time period
  - AIRS L2, ASCAT Wind, MUR 1km SST, TPW from Metop-B, NOAA-18 and NOAA-19, microwave brightness temperature from AMSR2, GMI, SSMIS, AAMH Microwave sounder data product from AMSU-A and MHS, IMERG GPM, MODIS AOT from Terra, SMAP wind speed, and JPL Rain Indicator product.
- The latest CPEX science quality data is available from the instrument PIs
  - HAMSR, APR3, dropsonde, DAWN and DC8 flight tracks.
- Daily GFS forecast at 00Z for 120 hours at every 12 hours interval
  - Relative humility, temperature, wind vectors, vertical velocity and height at different pressure levels

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CPEX Data Portal

https://cpexportal.jpl.nasa.gov

- Displays NRT satellite data, model forecast, and airborne data products on a 3D global Earth using Cesium (a Google Earth-like web-based 3D Virtual Globe Platform).
- Overlays multiple types of products with opacity adjustment and separate calendars for model and data for easy comparison.
- Allows access to raw data associated with the images for interactive analysis. Subsetting tools are built in so users can select circular or rectangular areas, lines, or points on the globe.
  - MySQL and Solr databases are used to provide temporal and geospatial search to find the satellite swaths that intersect with the selected area.
- Supports data exploration and visual investigation of all the relevant data products that describe the physical processes in the CPEX domain before, during, and after the campaign.